High-resolution, Antarctic Ice Sheet simulations forced by submarine melting simulated by the Accelerated Climate Model for Energy (ACME)

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Model simulations conducted on Edison & Cori at NERSC

U.S. DEPARTMENT OF ENERGY
Office of Science

ACME
Accelerated Climate Modeling for Energy

SciDAC
Scientific Discovery through Advanced Computing

Background / Motivation

Models & Configurations

Low-resolution results

High-resolution results

Summary & Future Work

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Low-resolution results

High-resolution results

Summary & Future Work

Background / Motivation

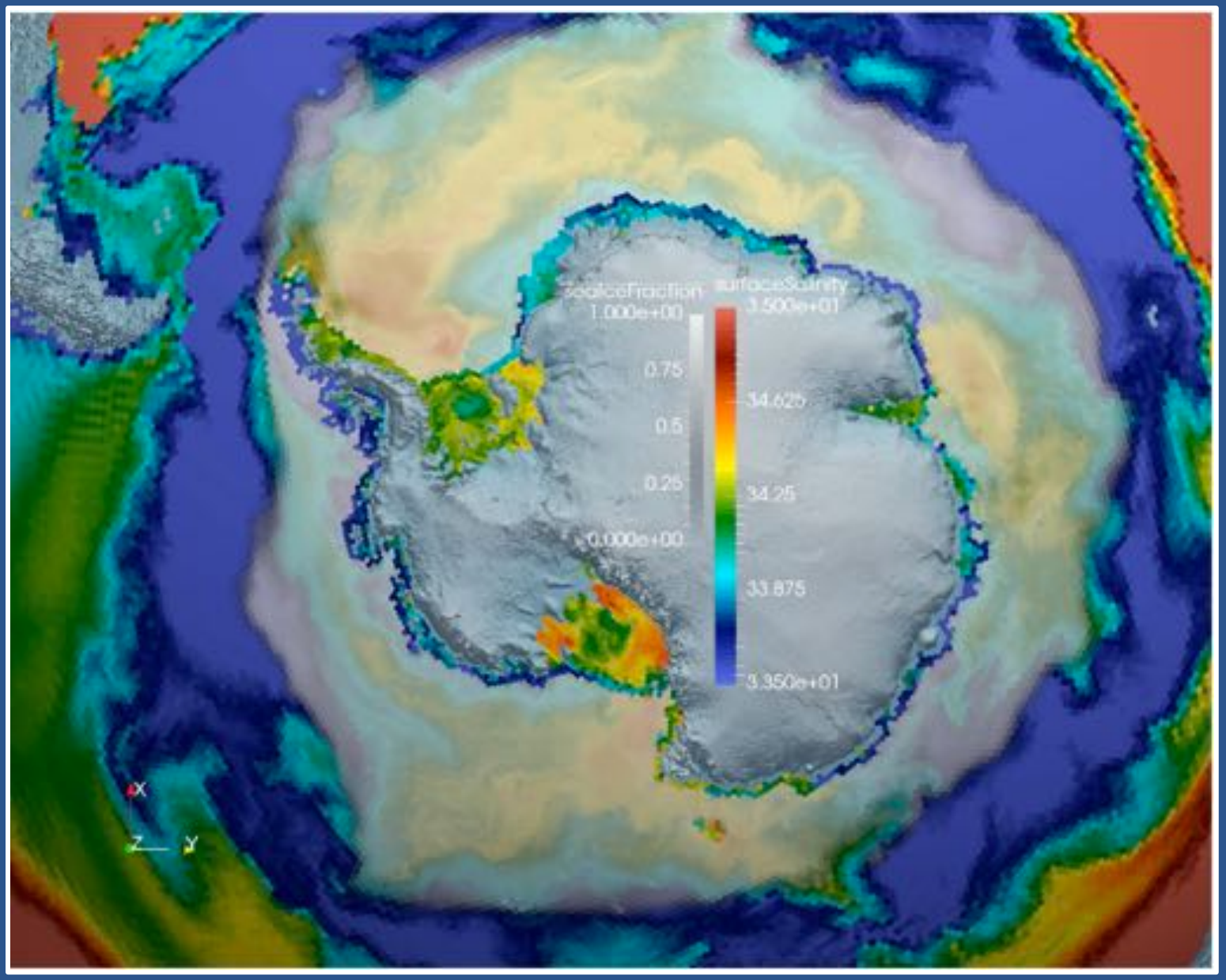
DOE's *Accelerated Climate Model for Energy* (ACME) project:

- Multi-lab effort to develop / apply ESM for DOE mission needs
- Technical focus: high-resolution, next generation HPC
- Science focus areas:

1. How do the hydrological cycle and water resources interact with the climate on local to global scales?
2. How do biogeochemical cycles interact with global climate change?
3. ***How do rapid changes in cryosphere-ocean systems interact with the climate system?***

We apply capabilities developed under (3) along with ice sheet models (from DOE PISCEES) to investigate sub-shelf melt and ice sheet mass balance sensitivity to changes in S. Ocean wind forcing

Sub-Ice Shelf Circulation in Fully-Coupled ESM



Background / Motivation

Development to allow for dynamic ice sheets in ACME is ongoing …

… but good science can be done with the existing capability for simulating ocean circulation beneath “static” ice shelves, e.g.

1. Examine differences in southern ocean water mass transformation, sea ice properties & trends, in simulations with and w/o ice shelf cavities
2. Apply idealized perturbations (e.g. wind stress, tropical-to-polar teleconnections) to explore how coupled climate impacts ice shelf melting and ice dynamics

A motivating example: Spence et al. (*GRL*, **41**, 2014)

Background / Motivation

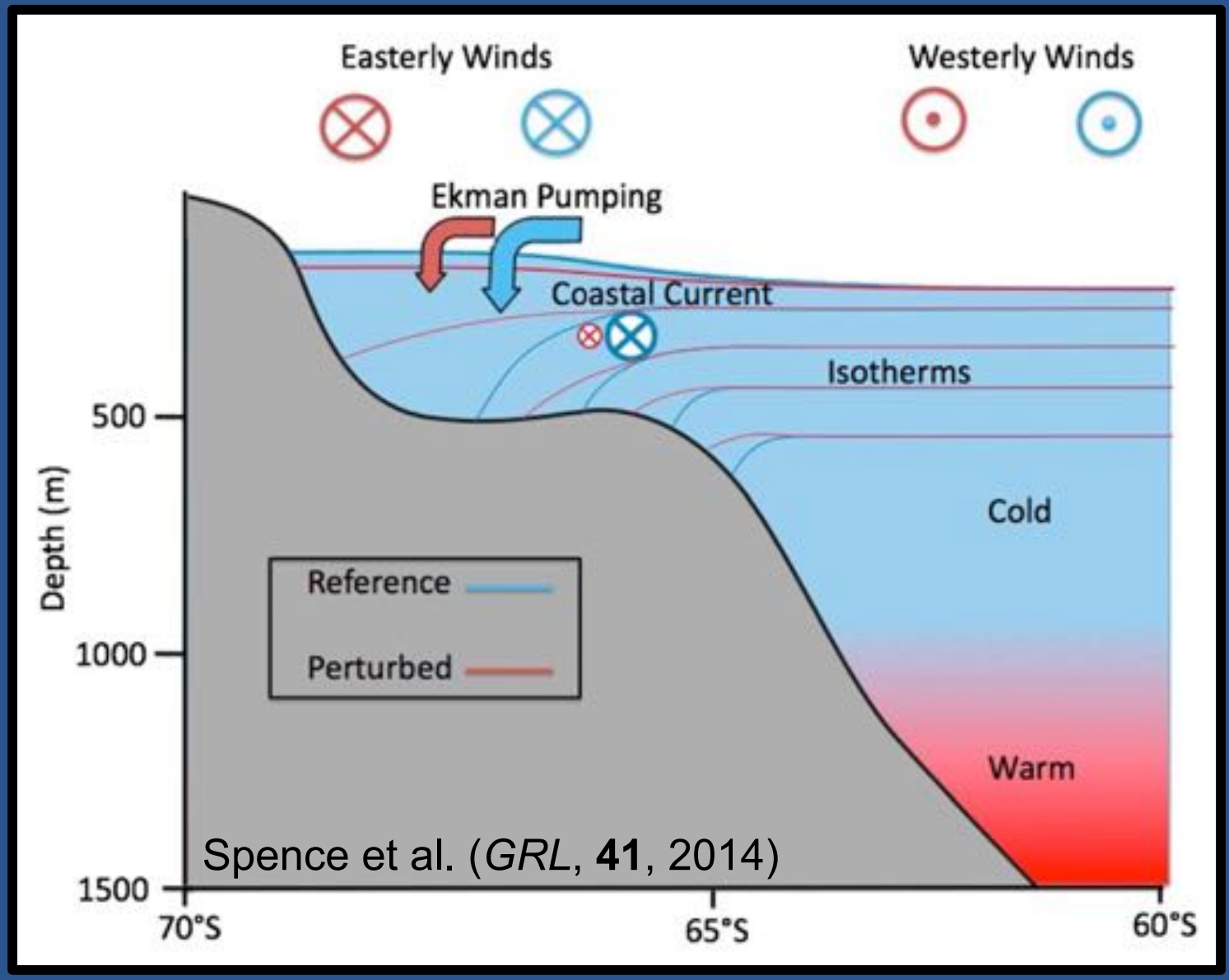
Southern Annular Mode has been trending positive since late ’50’s, with associated poleward shifting and strengthening of S. Hemis. westerly winds (Fyfe et al., 2007)

Continuation of this trend into the future is a robust feature of climate models under anthropogenic forcing (Zheng et al., 2013)

A continuation of this trend would impact the strength and stability of the *Antarctic Slope Front* (ASF), which currently limits the access of warm, intermediate depth waters to Antarctic continental shelves (e.g., Helmer et al., 2012)

Spence et al. (2014) show sensitivity of the ASF to anticipated S. ocean wind shifts and resultant warm water upwelling around coastal Antarctica

Background / Motivation

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Models and Configurations

Model for Prediction Across Scales (MPAS):

- MPAS-Ocean (Ringler et al., *Ocn. Mod.*, **69**, 2013)
- MPAS-Sea Ice (Turner et al., in prep.)
- MPAS-Land Ice (Hoffman et al., in prep.) + Albany/Trilinos dycore (Tezaur et al., 2015a,b; Tuminaro et al., 2016)

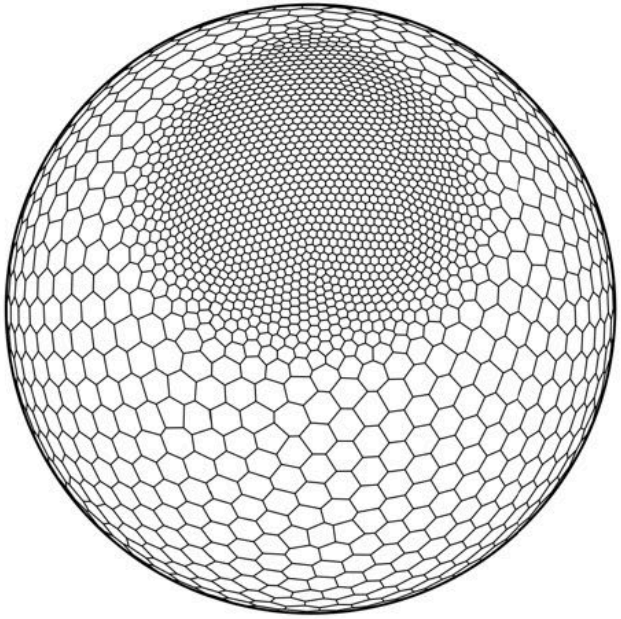
Data atmos. (T62), fluxes & winds = CORE-Normal Year**

Control: standard CORE-NY forcing

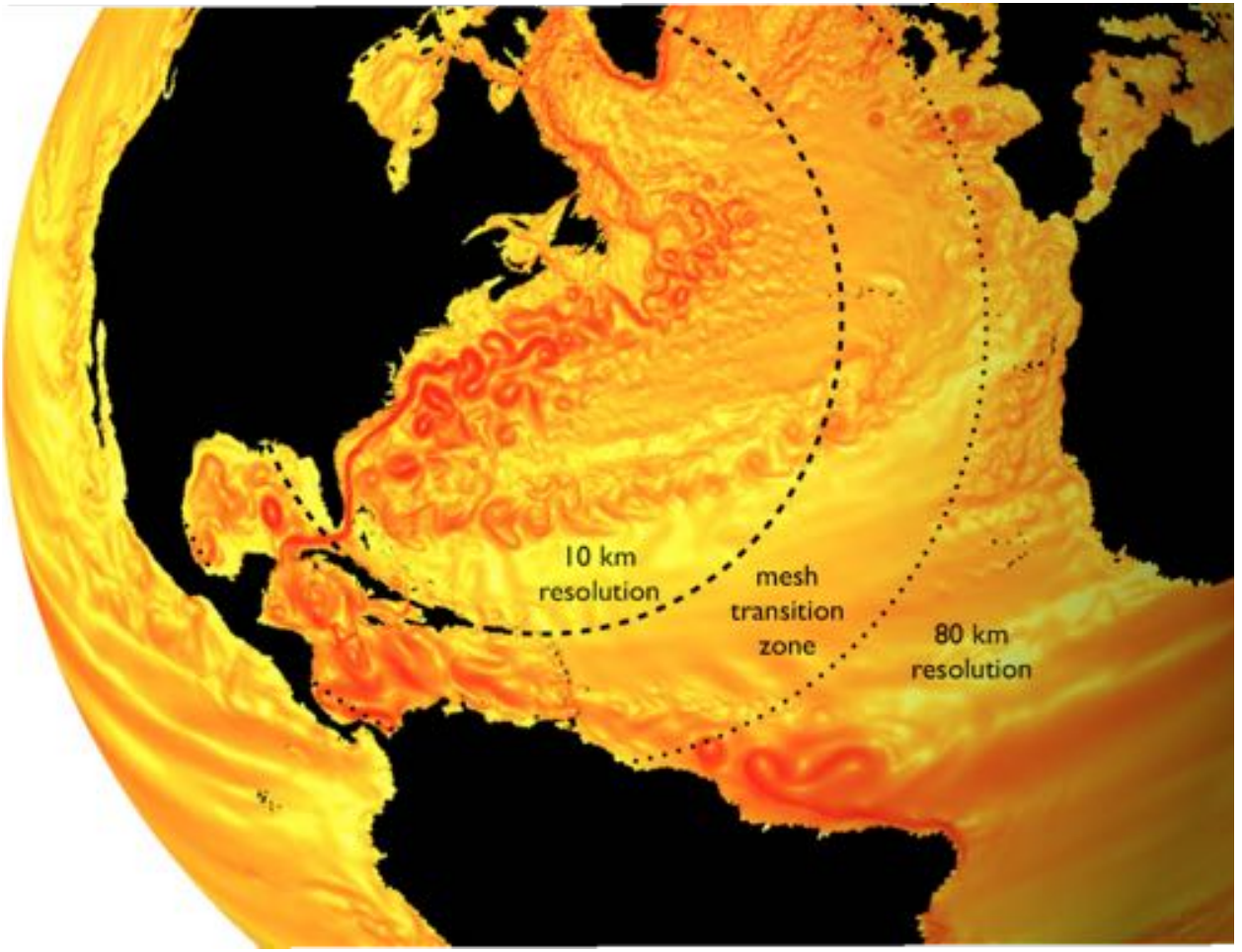
Perturbation: sfc winds shifted south, increased, or both++

** 1 yr climatological mean atoms. state (Yeager and Large, *Clim. Dyn.* **33**, 2009)
++ Spence et al. (2014)

Models and Configurations



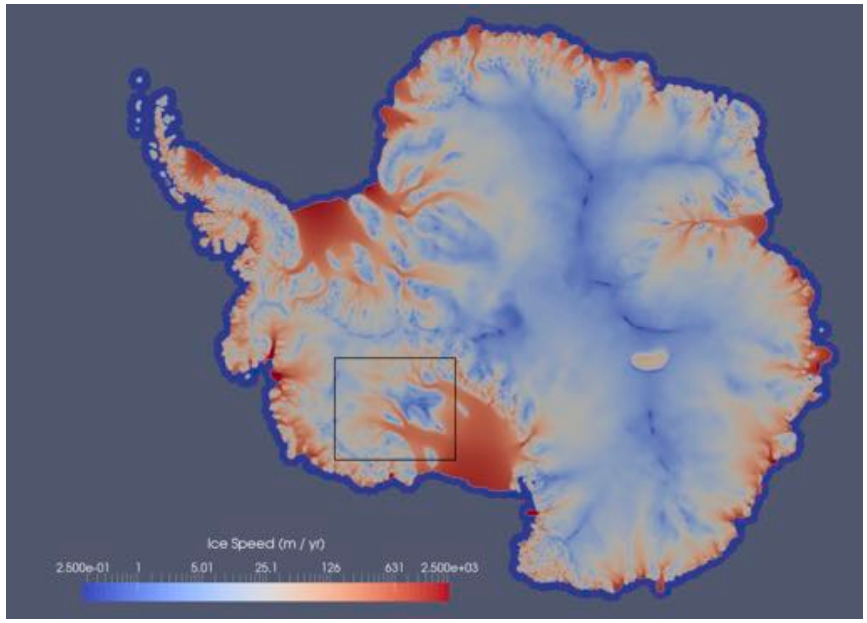
Spherical Centroidal Voronoi Tesselations (SCVT)

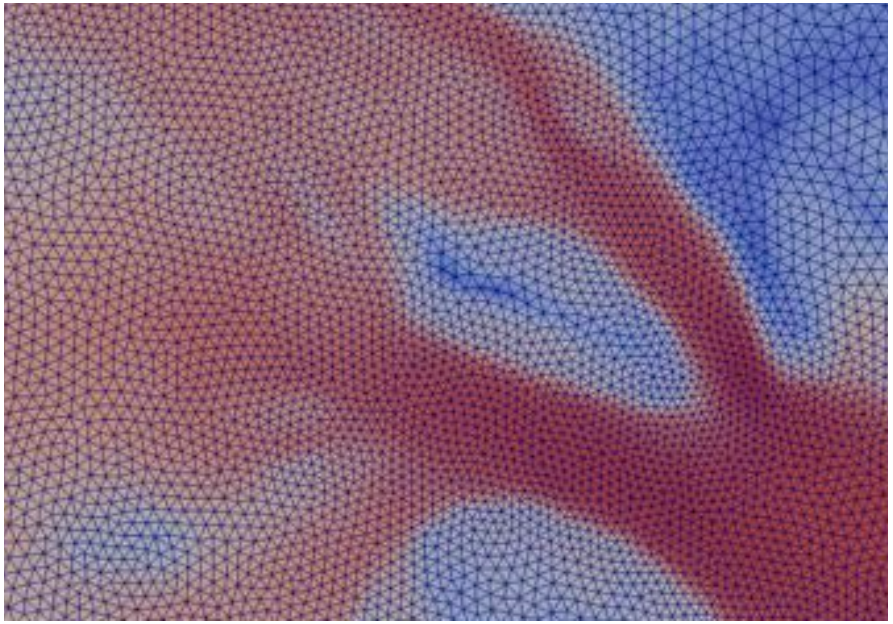


oEC60to30km:
60 km res. at equator,
30 km res. at poles
(~1° POP)

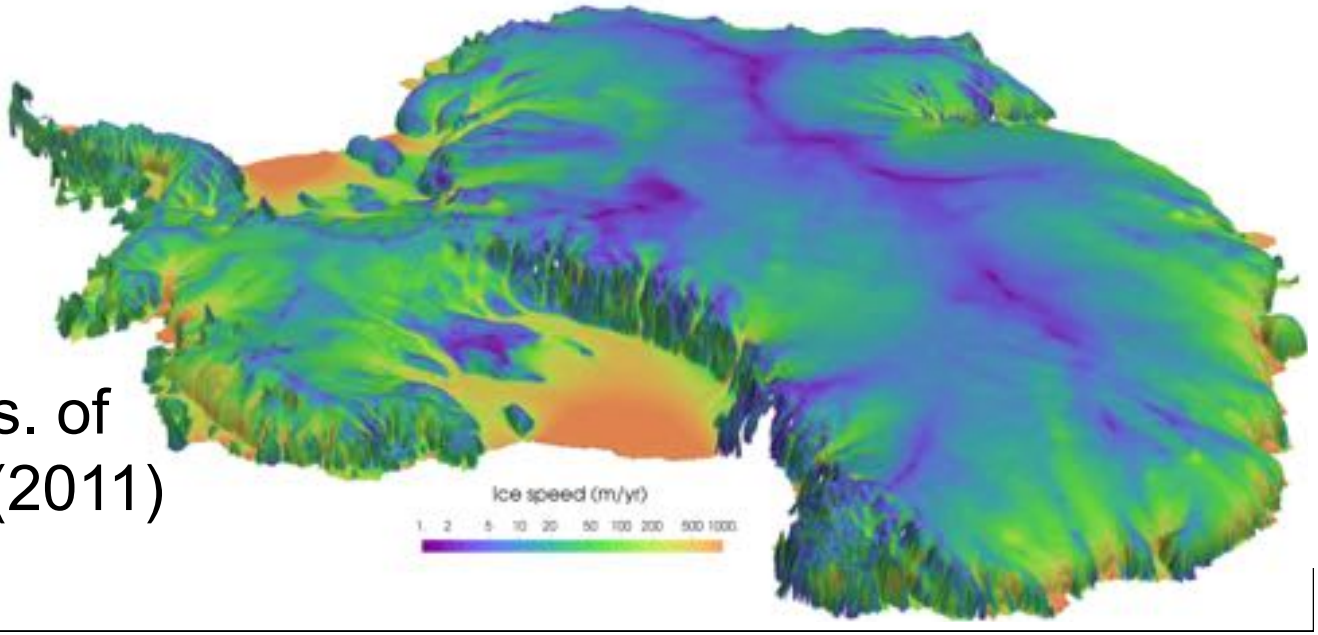
oRRS30to10km:
30 km res. at equator,
10 km res. at poles
(~1/10° POP)

Models and Configurations





14-4 km (med. res.)
30-1 km (high res.)



Initial velocities
optimized to obs. of
of Rignot et al. (2011)

Models & Configs: low-resolution

	Ocean & Sea Ice	Ice Sheet
Low Resolution	oEC60to30km	ais20km
Med. Resolution	oRRS30to10km	aisVR14to4km
High Resolution	oRRS18to6km	aisVR30to1km

Data atmosphere & runoff at T62 resolution

Models & Configs: high-resolution

	Ocean & Sea Ice	Ice Sheet
Low Resolution	oEC60to30km	ais20km
Med. Resolution	oRRS30to10km	aisVR14to4km
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Data atmosphere & runoff at T62 resolution

Models & Configs: high-resolution

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Data atmosphere & runoff at T62 resolution


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Low-Resolution Results

Low-resolution, “proof-of-concept” simulations using oEC60to30km resolution ocean / sea ice

Simulations and forcing as in Spence et al. (2014)

Two ~10 yr simulations conducted

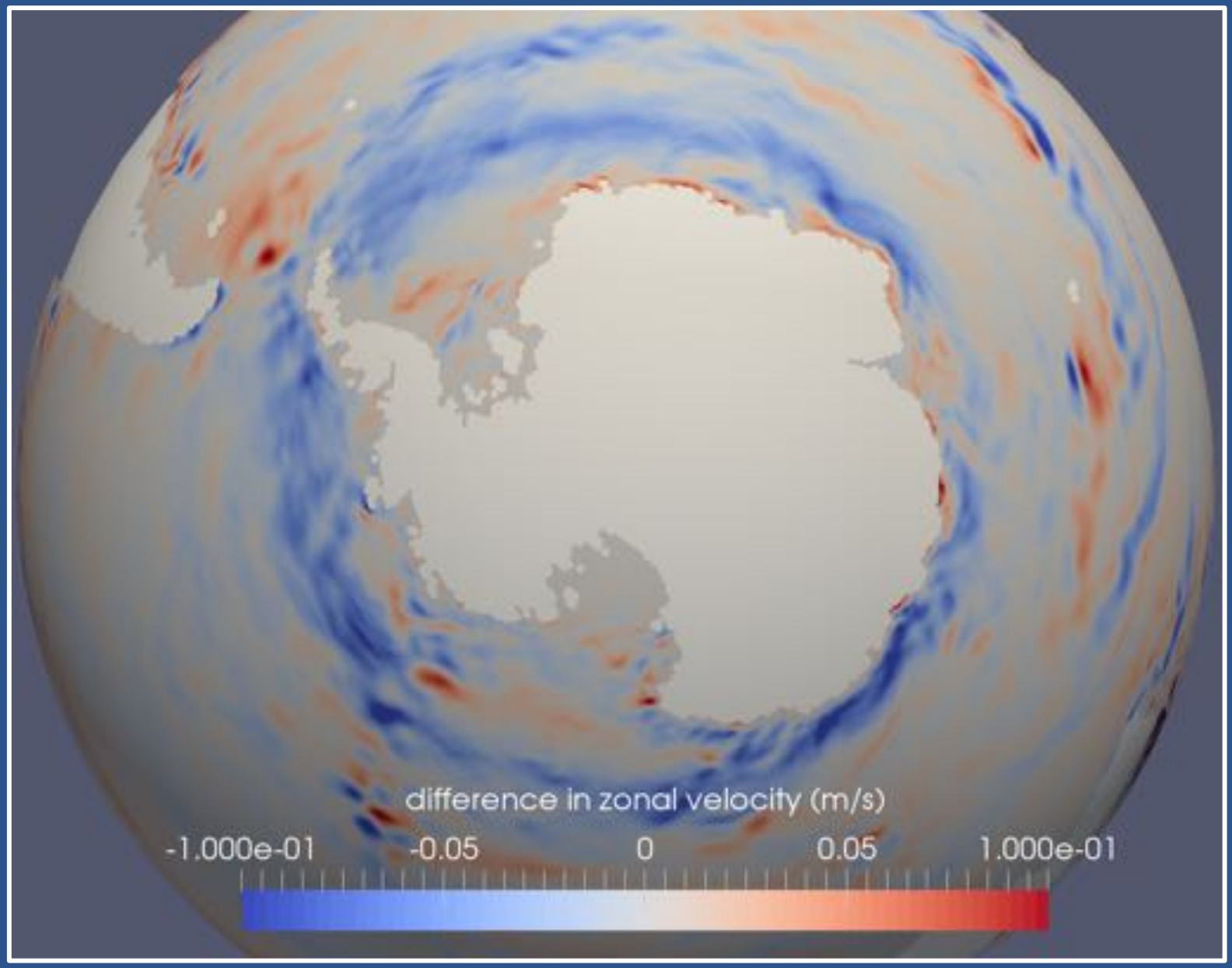
Compare mean zonal winds and submarine melt rate anomalies at yr 10

Force med. resolution (14-4 km) AIS model for 100 yrs:

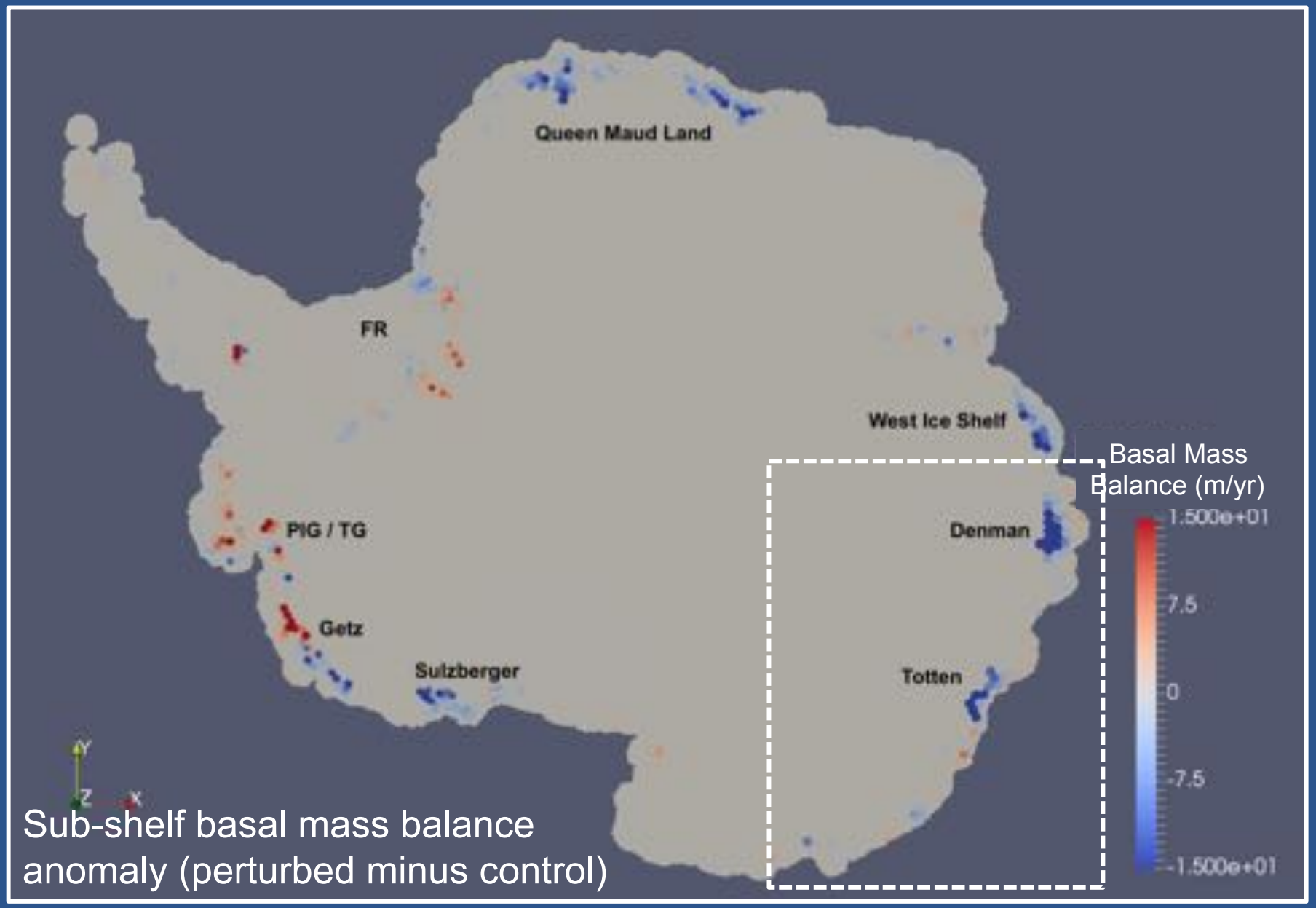
- RACMO2 mean surface mass balance from 1979-2010 (Lenaerts et al., 2012)
- ACME sub-ice shelf melt rates from control and perturbed winds simulations

Difference ice sheet model results for two different forcings

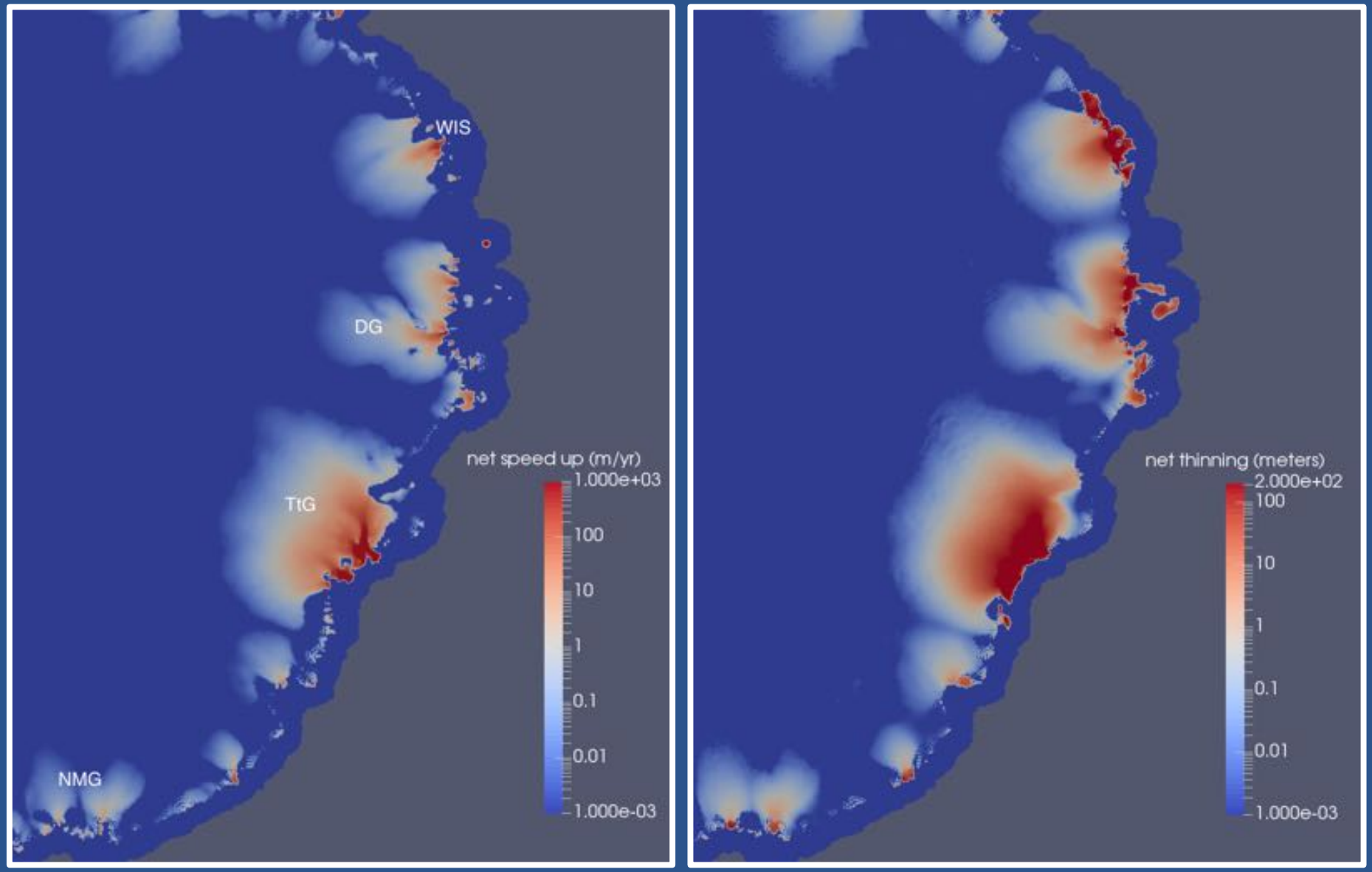
Low-Resolution Results



Low-Resolution Results



Low-Resolution Results



Ice sheet speed (left) & thinning anomalies (right) after 100 yrs

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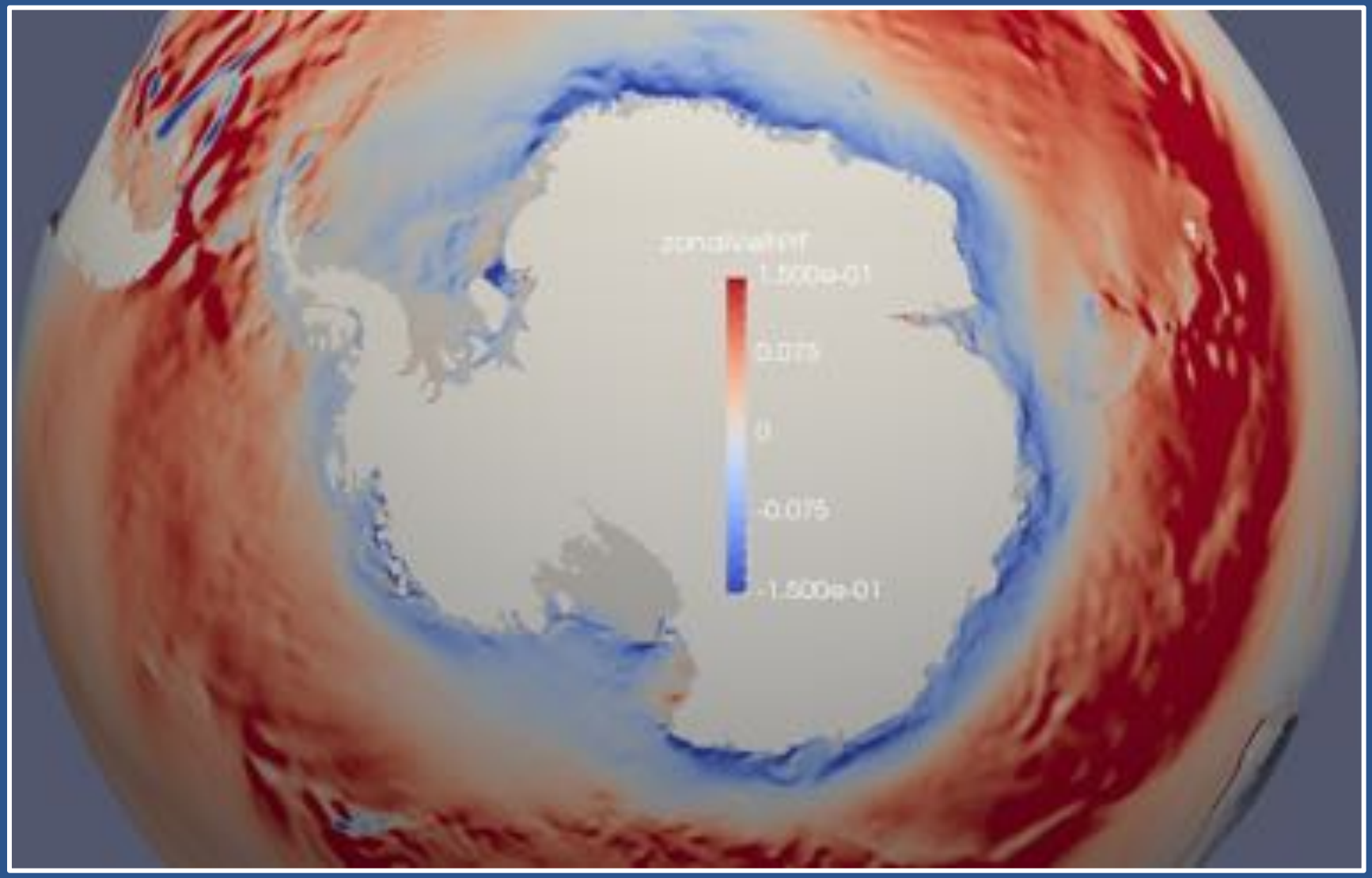
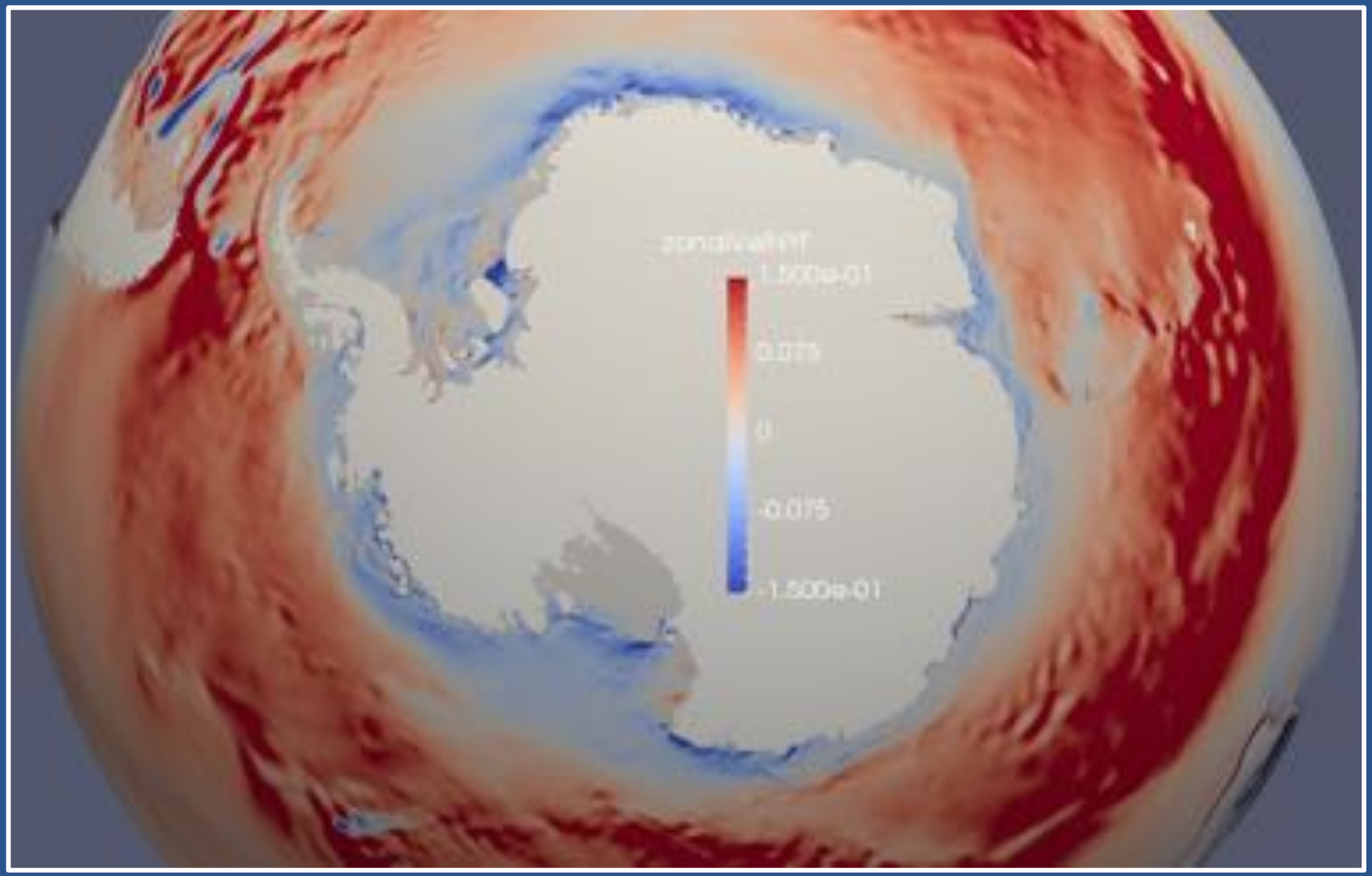
High-Resolution Results



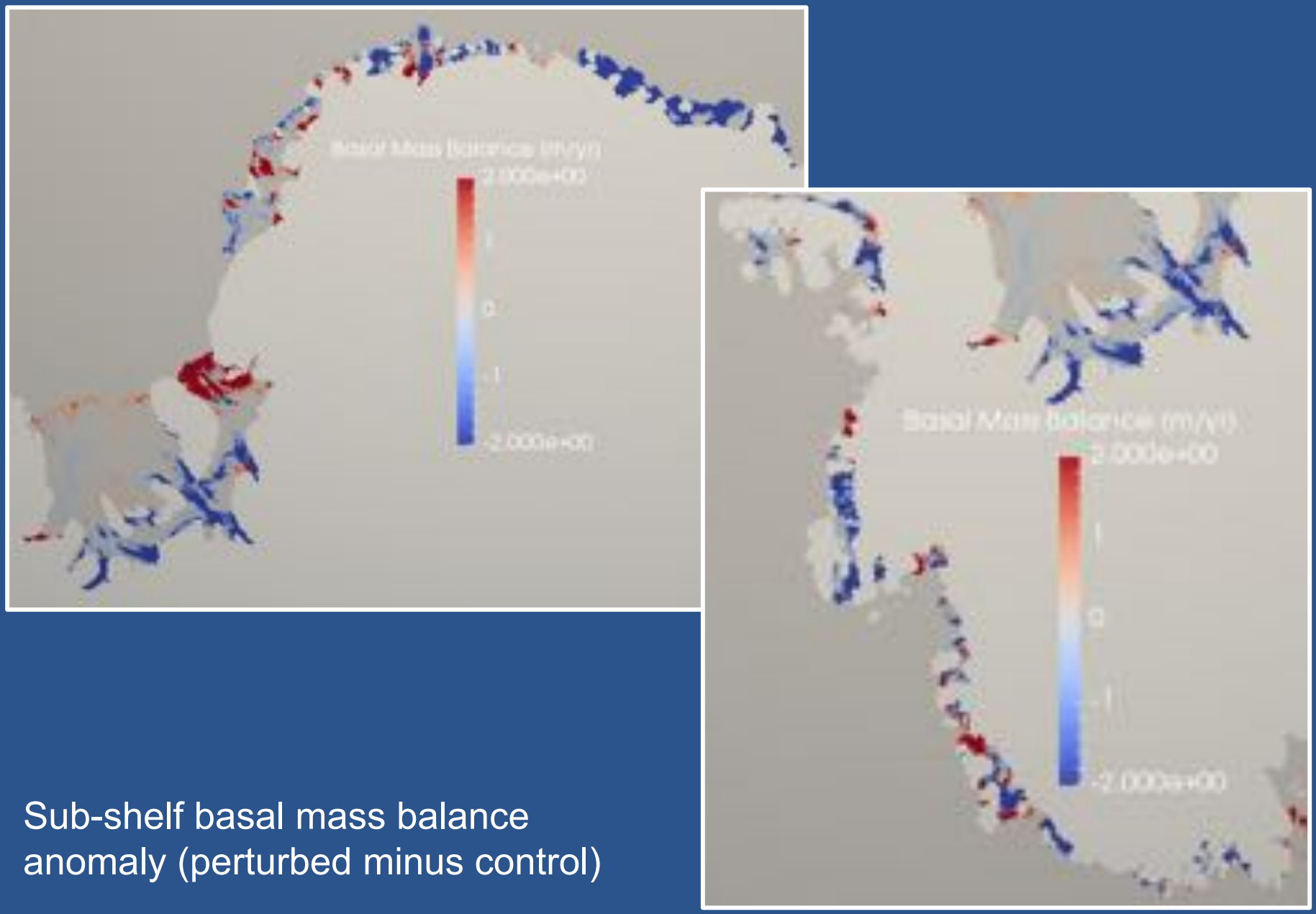
Zonal Velocity (control run)

High-Resolution Results



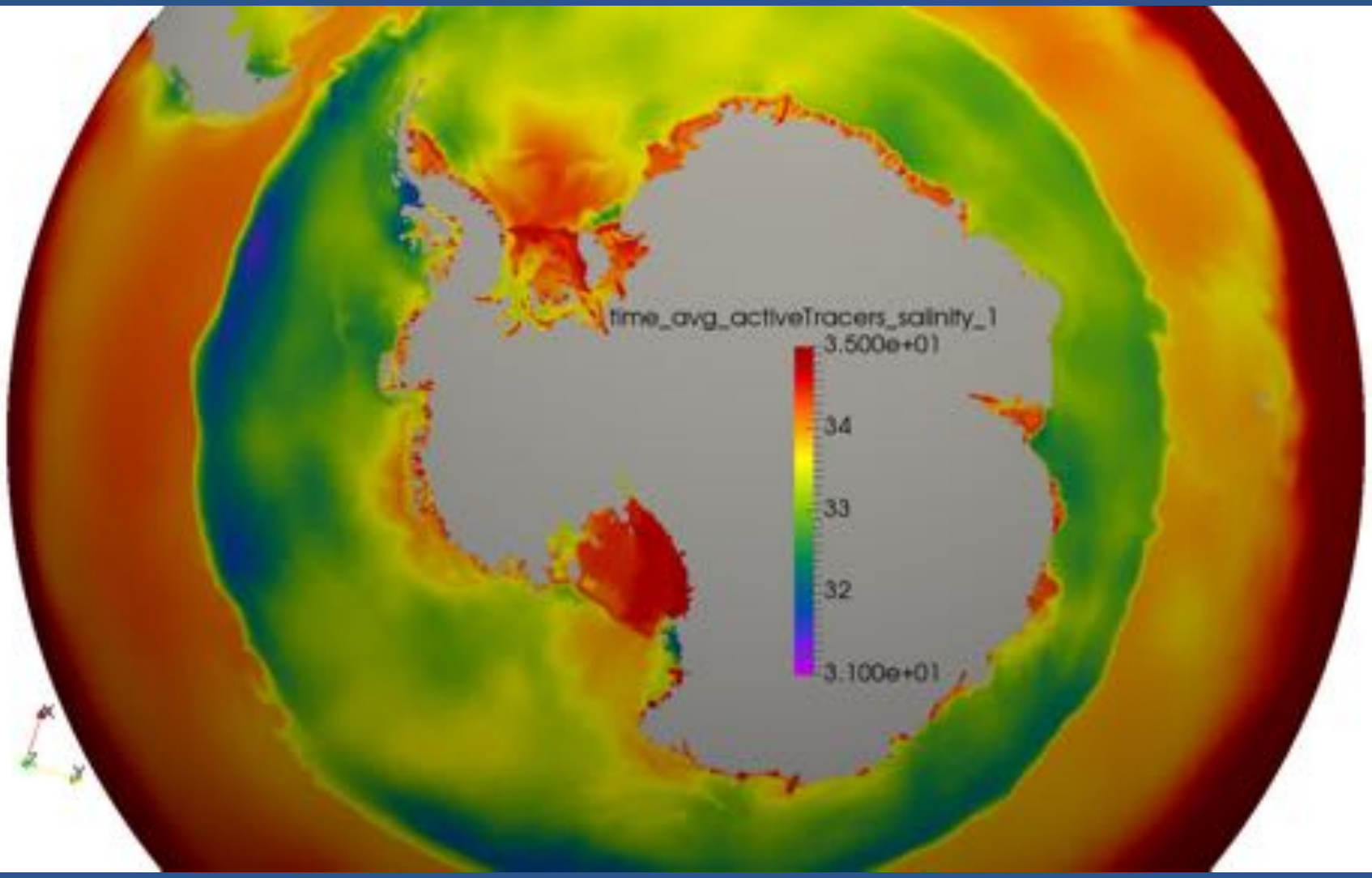
Zonal Velocity (perturbed winds)

High-Resolution Results



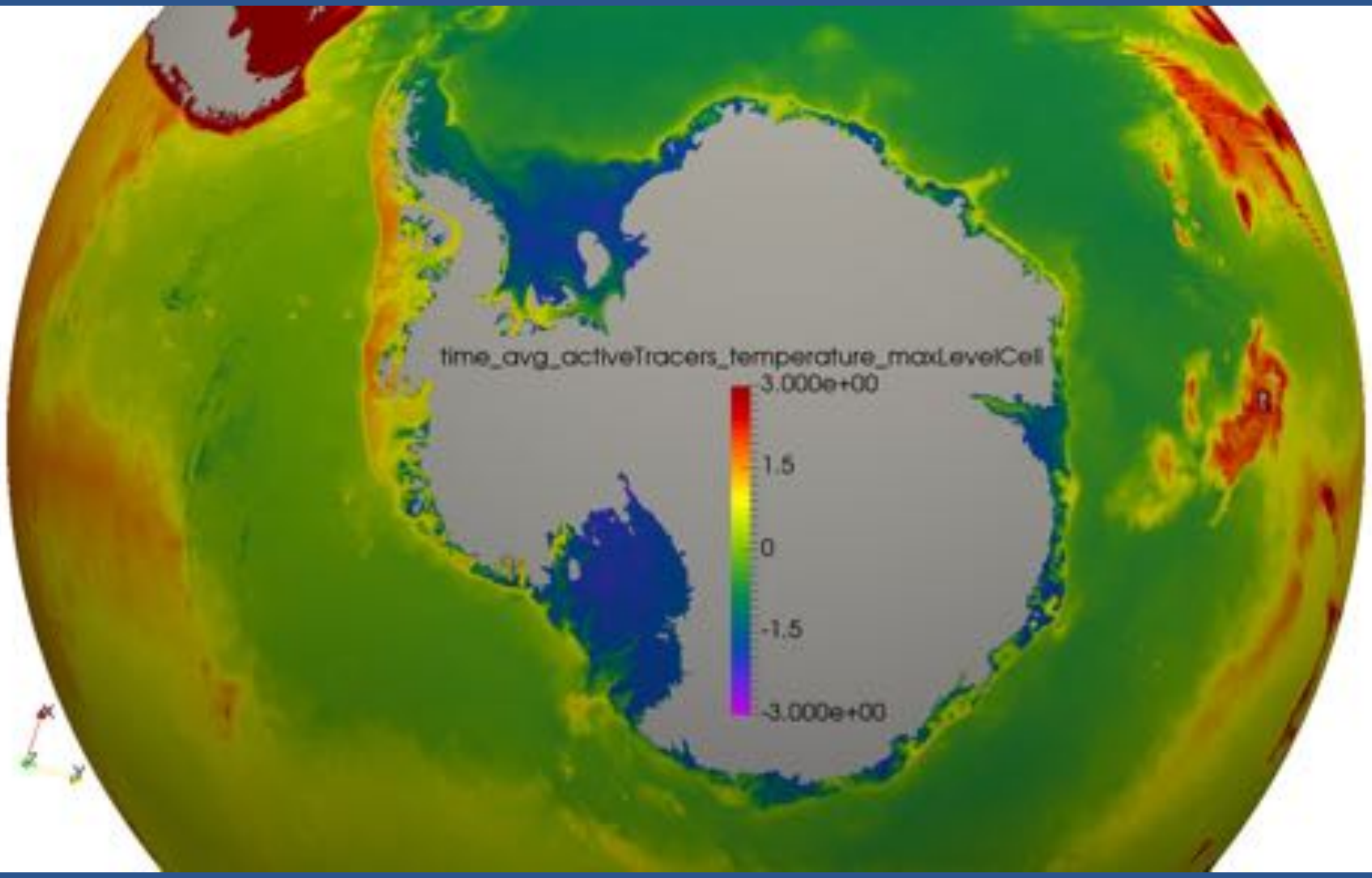
Sub-shelf basal mass balance anomaly (perturbed minus control)

High-Resolution Results



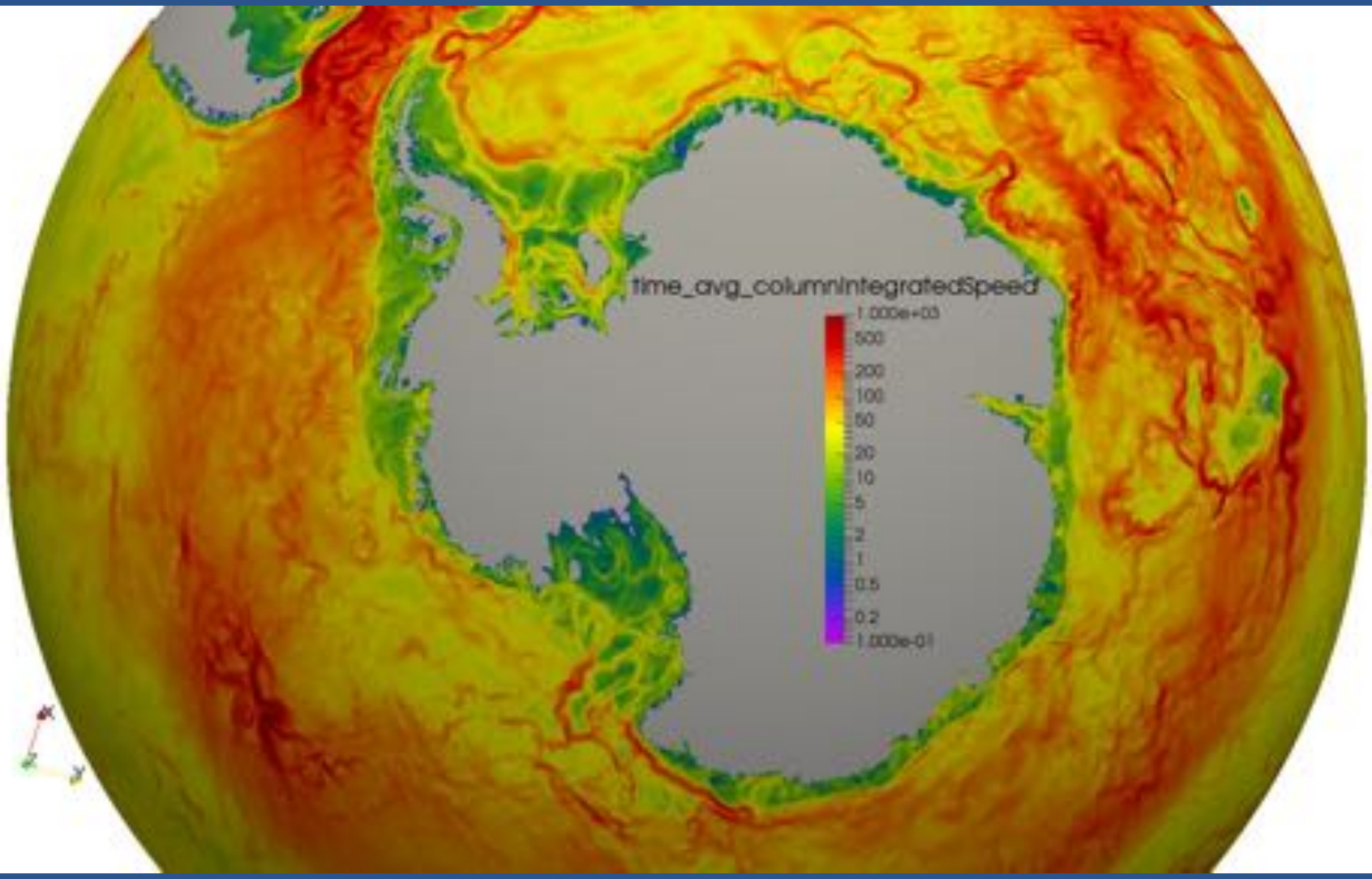
sea surface salinity over ~6 yrs

High-Resolution Results



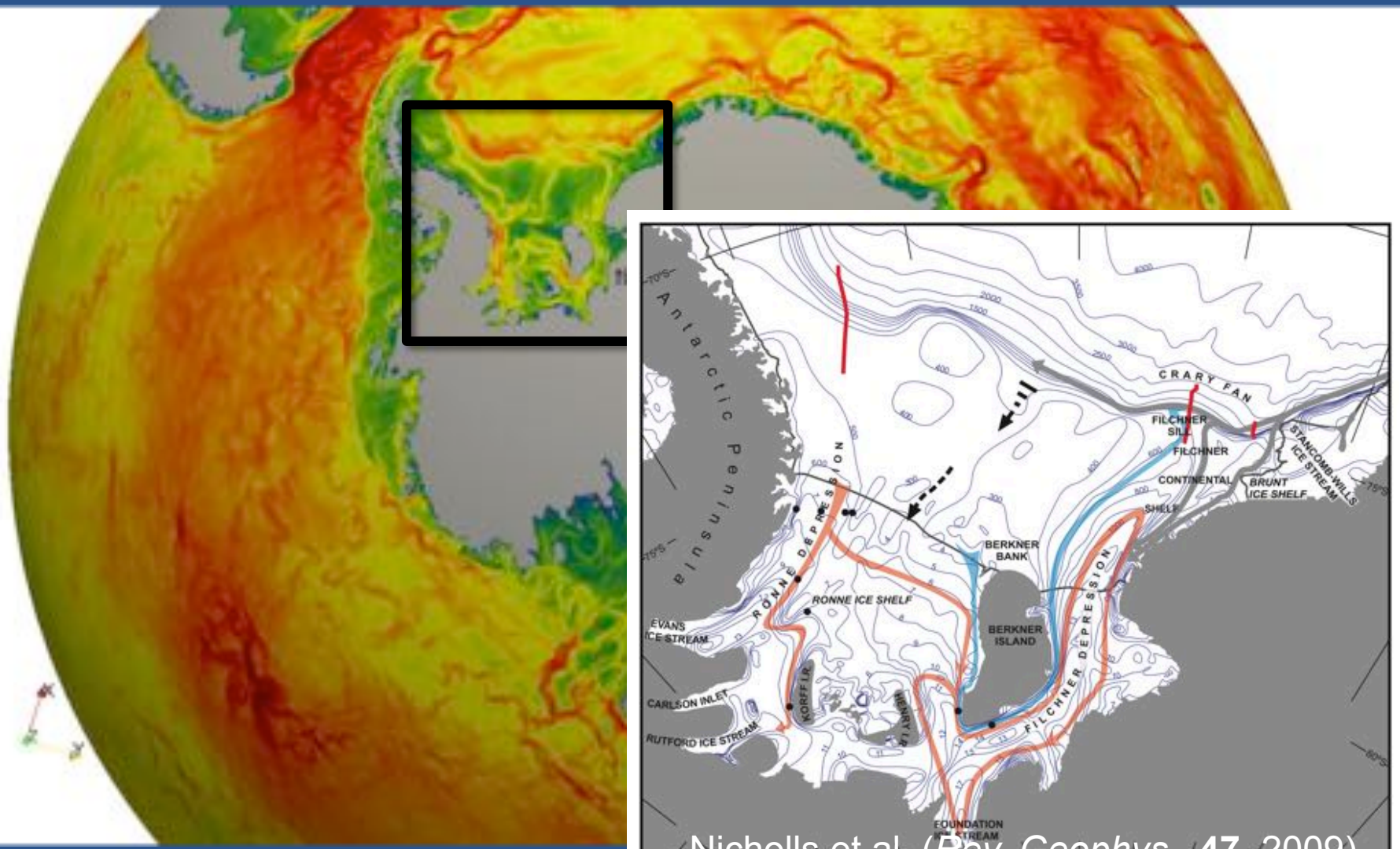
ocean bottom temperature over ~6 yrs

High-Resolution Results



transport (column integrated speed) over ~6 yrs

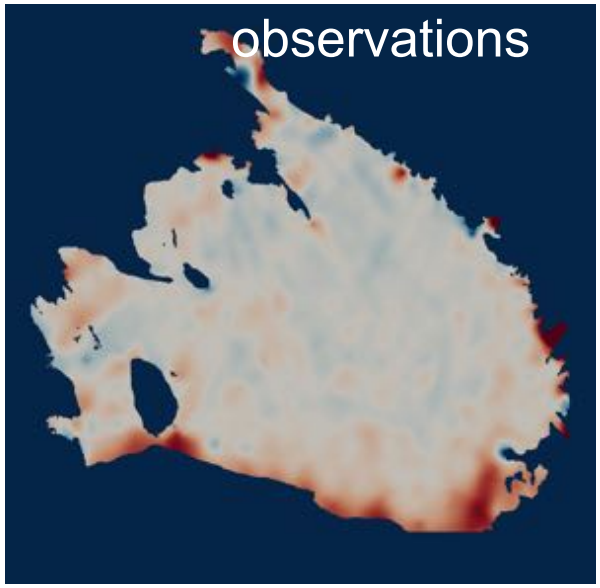
High-Resolution Results

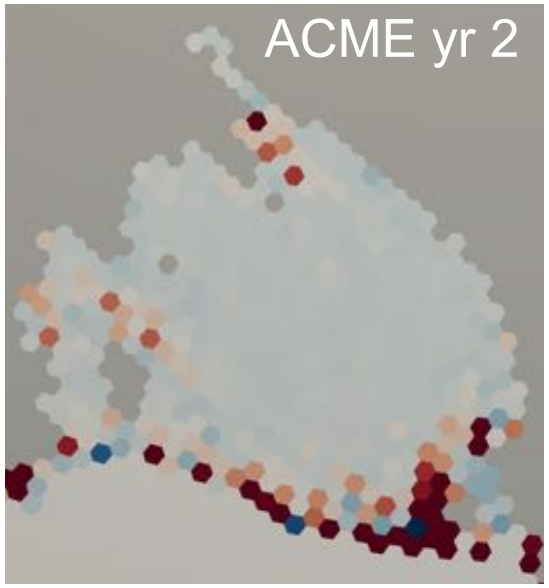


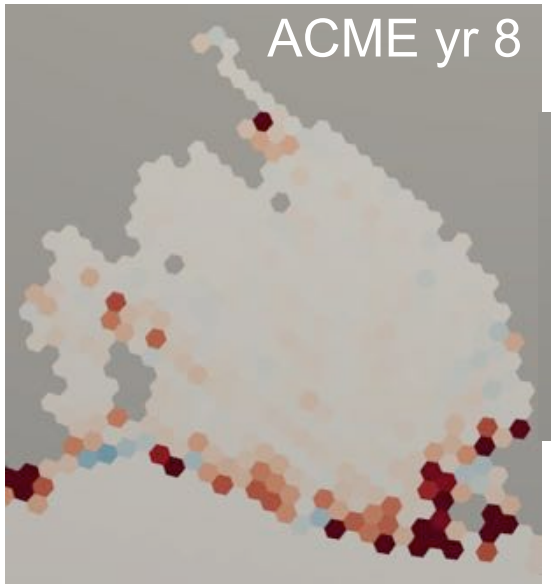
Nicholls et al. (*Rev. Geophys.*, **47**, 2009)

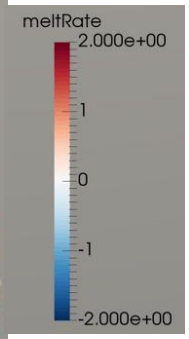
Transport over ~10 yrs (control simulation)

Melt Rates (low-resolution)



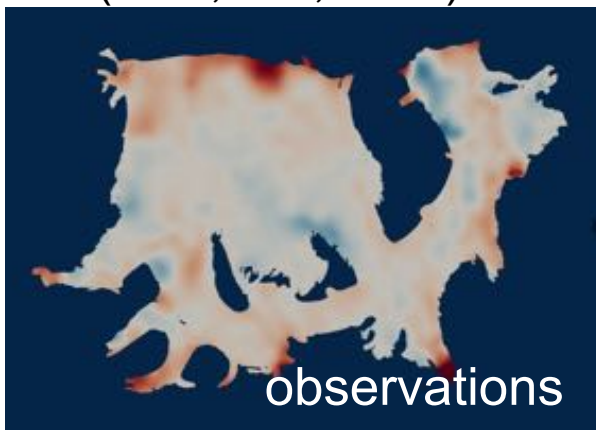


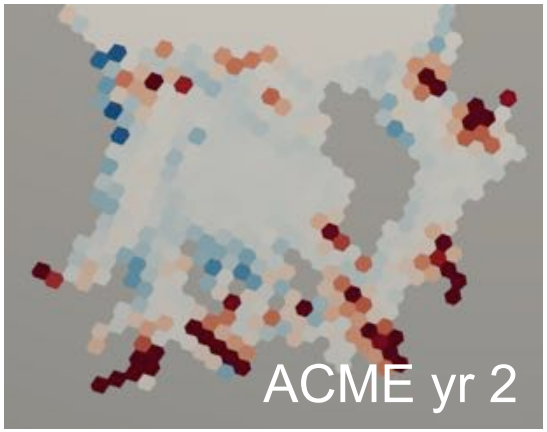


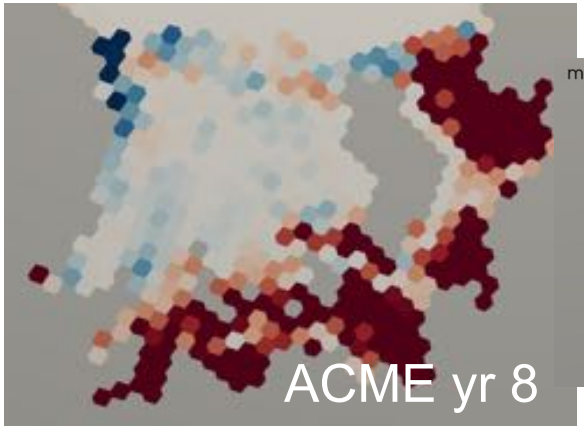


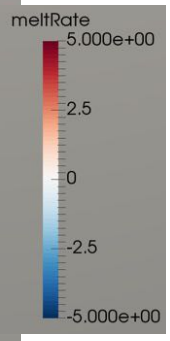
after Moholdt et al.
(*GRL*, **119**, 2014)

Ross Ice Shelf









Filchner-Ronne Ice Shelf

Low-Resolution Results

	ACME	Study 1	Study 2	Study 3
Ross	-94	-50(64)	-48(15)	-34(25)
Filchner-Ronne	-435 [-2375]	-124(66)	-155(22)	-50(30)

Study 1: Moholdt et al. (*GRL*, **119**, 2014)

Study 2: Rignot et al. (*Science*, **341**,2013)

Study 3: Depoorter et al. (*Nature*, **502**, 2013)

Summary & Future Work

- Submarine melt changes forced by wind-stress changes (anticipated by Spence et al., 2014) are realized within a global, coupled model with circulation in ice shelf cavities

- Large melt rate biases (warm water flooding ice shelf cavities):
  - Longer spin-up needed?
  - Coastal countercurrent resolution?
  - Runaway ice-shelf pump → spin-up initially w/o melting?
  - Mixed layer shoaling (as seen in POPSICLES)?
  - Other coupled model biases?

Summary & Future Work

- Longer term goals:
  - Optimize ice sheet for initial equilibrium under non-perturbed wind forcing
  - Re-run forward ISM simulations under perturbed wind forcing on hi-res. mesh
  - Iterate offline-evolved ice shelf cavity shape with ACME model runs in order to provide realistic, high resolution, submarine melt fields for use in offline-forced ISM runs

- Difficulties in simulating / maintaining ASF in front of Filchner-Ronne + ice sheet sensitivity to submarine melting in this region (Martin et al., AGU Wed.) suggest extreme vulnerability of this sector of the ice sheet to ocean circulation changes (?)